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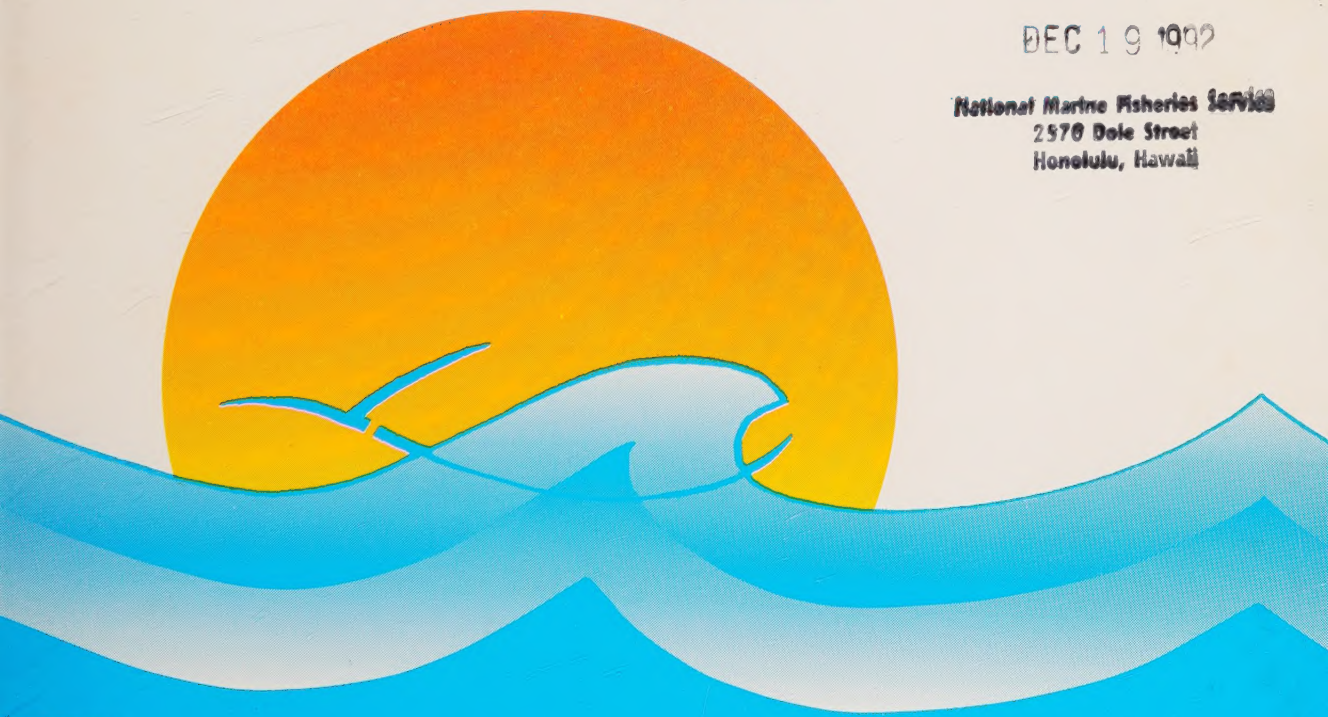

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SEA FISHERIES RESEARCH INSTITUTE
DEPARTMENT OF ENVIRONMENT AFFAIRS
SOUTH AFRICA

Republic of South Africa
Department of Environment Affairs
SEA FISHERIES RESEARCH INSTITUTE

RESEARCH HIGHLIGHTS 1991/92

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Cape Town 1992

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Published in 1992 by the Sea Fisheries Research Institute,
Private Bag X2, Rogge Bay 8012, Cape Town

Research Highlights 1991/92

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ISBN 0 621 11167 8

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Printed for the Government Printer
by
Galvin & Sales, Cape Town
(8415)

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The text was compiled by the editors under the guidance of the Institute's Research Steering Committee. Inputs were made by the following staff members: C. J. Augustyn, A. Badenhorst, G. W. Bailey, H. G. van D. Boonstra, A. J. Boyd, P. C. Brown, K. L. Cochrane, R. J. M. Crawford, J. H. M. David, L. Hutchings, L. F. Jackson, D. W. Japp, R. W. Leslie, M. R. Lipiński, D. G. M. Miller, A. G. S. Moldan, P. M. S. Monteiro, A. I. L. Payne, A. J. Penney, D. E. Pollock, R. Melville-Smith, M. J. Roberts, R. H. Simons, R. J. Q. Tarr, J. Taunton-Clark. The Director of the Sea Fisheries Research Institute, Dr L. V. Shannon, wrote the introduction and laid down general guidelines.

MISSION OF THE SEA FISHERIES RESEARCH INSTITUTE

The Sea Fisheries Research Institute advises on the optimal utilization of living marine resources and the conservation of marine ecosystems by conducting and supporting relevant multidisciplinary scientific research and monitoring in the marine environment. Sustainable utilization and the need to preserve future options regarding the utilization of marine ecosystems and their resources are guiding objectives in the research and advice of the Institute. In order to achieve its goals, the Institute advises and interacts with decision-makers, the fishing industry, interest groups and the local and international scientific community. The Institute conducts its activities in an open and cooperative manner, functions within the Department of Environment Affairs and strives for excellence in its research and advice.

1. INTRODUCTION

THE Sea Fisheries Research Institute has changed during the past year. One of the changes is the appearance of a new title, *Research Highlights*, which is the response of the Institute to feedback from our "clients" in the South African public and private sectors on the *Research Biennium* and *Annual Report* series. As such it replaces the former and the research component of the latter. *Research Highlights* is not a record of all the Institute's activities during the year, but its intention is rather to focus attention on the principal issues and on topical items. The comprehensive research record appears in the primary scientific literature (a list of papers published by Institute staff is appended), whereas the general reporting on activities in terms of our public accountability is adequately catered for in the *Annual Report of the Department of Environment Affairs*, as tabled in Parliament.

The Institute has also changed in other ways. During 1991/92, agreement was reached on a new organizational structure which permits the operational procedures which we have developed over the past few years to be implemented fully. This structure has been achieved without additional posts or funds. The changes are intended to make the Institute's research, assessments and monitoring more focused within its line-function and more cost-effective. The old and new organograms are compared conceptually in Figure 1. The various subdirectorates or functional groups, as we prefer to call them, are in essence the disciplinary homes of the scientists, engineers, technicians and support staff — the bureaucracy. Operationally the Institute now functions on a matrix basis (Fig. 2), the essential components being the Research Steering Committee and the Working Groups. This facilitates the proper direction and integration of all activities and enables us to respond rapidly to changing needs and circumstances. Institute scientists and experts from outside the Institute serve on the Working Groups.

The research structures have been supplemented by a suite of Industry-Sea Fisheries Research Institute Forums (INSEFs) which are intended to improve communication and to promote research cooperation and understanding between the various sectors of the fishing industry and our scientists. Together, the new organizational and operational structures and INSEF permit the Institute to draw on outside expertise and, in the process, marshall the collective wisdom so that the best possible scientific advice can be provided on the optimal utilization of living marine resources and the conservation of marine ecosystems.

As indicated in the last *Research Biennium*, changes have occurred during recent years in a number of resources as well as in the marine environment. These changes have been documented in a paper which will appear in the next number of the *South African Journal of Marine Science*. The major resource changes were the rise and subsequent decline in productivity of the anchovy *Engraulis capensis* and the general decline in availability of the West Coast rock lobster *Jasus lalandii*; accordingly, considerable research attention has been focused on these stocks. Fortunately, there was again good recruitment and survival of anchovy during 1991, following on two extremely poor years, and in November 1991 the spawner biomass was the second highest measured since hydroacoustic assessments started in 1984 — highlighting the key role played by environmental processes and the responsive management procedures formulated by the Pelagic Working Group. In contrast to anchovy, the West Coast rock-lobster resource remains depressed, with abnormally low rates

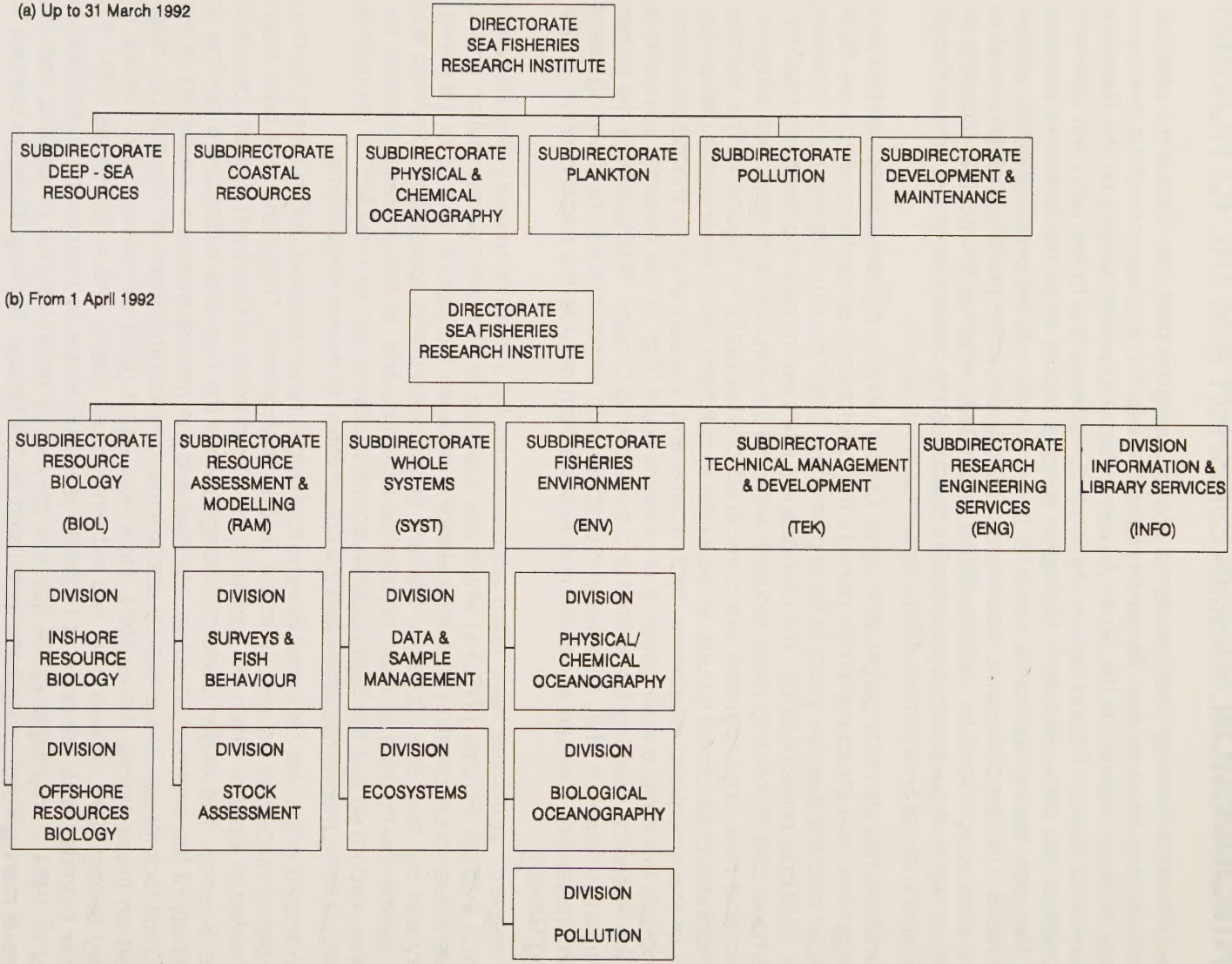
(a) Up to 31 March 1992
DIRECTORATE SEA FISHERIES RESEARCH INSTITUTE
SUBDIRECTORATE DEEP - SEA RESOURCES
SUBDIRECTORATE COASTAL RESOURCES
SUBDIRECTORATE PHYSICAL & CHEMICAL OCEANOGRAPHY
SUBDIRECTORATE PLANKTON
SUBDIRECTORATE POLLUTION
SUBDIRECTORATE DEVELOPMENT & MAINTENANCE
(b) From 1 April 1992
DIRECTORATE SEA FISHERIES RESEARCH INSTITUTE
SUBDIRECTORATE RESOURCE BIOLOGY (BIOL)
SUBDIRECTORATE RESOURCE ASSESSMENT & MODELLING (RAM)
SUBDIRECTORATE WHOLE SYSTEMS (SYST)
SUBDIRECTORATE FISHERIES ENVIRONMENT (ENV)
SUBDIRECTORATE TECHNICAL MANAGEMENT & DEVELOPMENT (TEK)
SUBDIRECTORATE RESEARCH ENGINEERING SERVICES (ENG)
DIVISION INFORMATION & LIBRARY SERVICES (INFO)
DIVISION INSHORE RESOURCE BIOLOGY
DIVISION OFFSHORE RESOURCES BIOLOGY
DIVISION SURVEYS & FISH BEHAVIOUR
DIVISION STOCK ASSESSMENT
DIVISION DATA & SAMPLE MANAGEMENT
DIVISION ECOSYSTEMS
DIVISION PHYSICAL/ CHEMICAL OCEANOGRAPHY
DIVISION BIOLOGICAL OCEANOGRAPHY
DIVISION POLLUTION

Fig. 1: Organizational structure of the Sea Fisheries Research Institute (a) up to 31 March 1992, and (b) from 1 April 1992

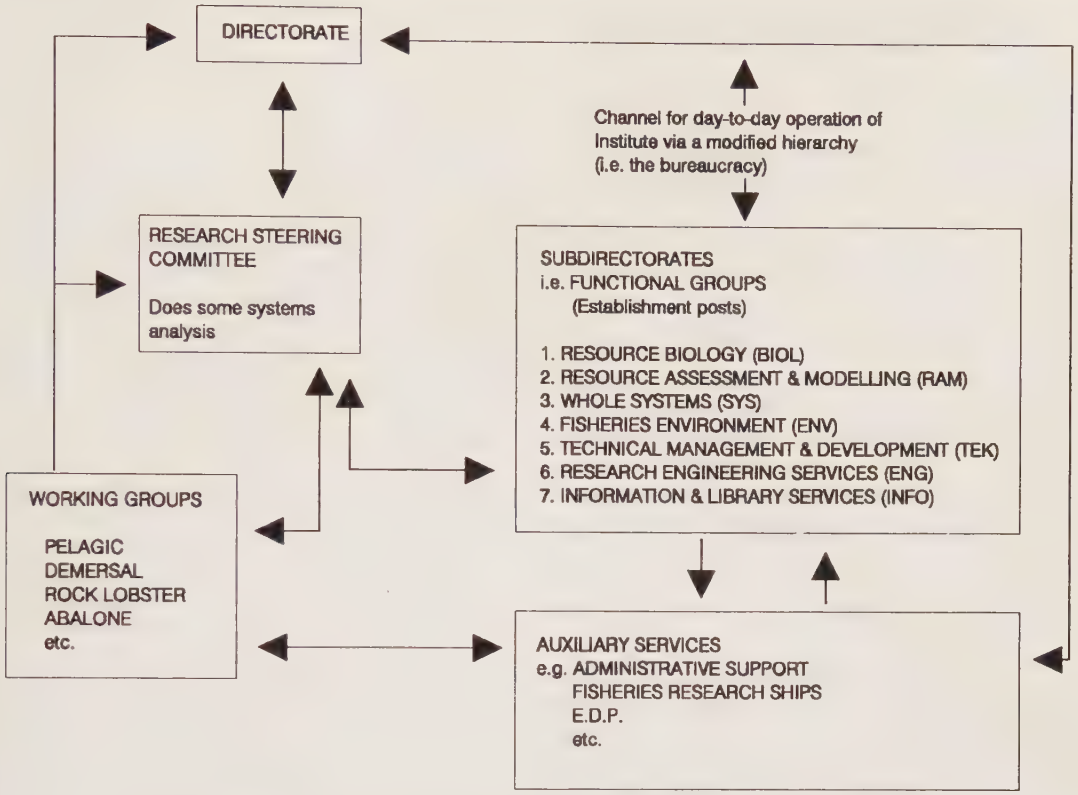

Fig. 2: Matrix of the functional components of the Sea Fisheries Research Institute

of growth continuing. This has precipitated a complete re-think of the scientific basis for the management of the resource — the size limit, the allowable commercial catch, the recreational fishery, the role of sanctuaries, and so on. The debate continues.

Before moving on to the research highlights *per se*, it is appropriate to comment briefly on aspects of the Institute's infrastructure. In the early 1980s the research ship fleet consisted of five vessels — *Africana* (the flagship), *Benguela*, *Sardinops*, *Trachurus* and *Kunene*. *Kunene* was decommissioned in 1982, and in 1990 *Benguela* was returned to the Namibian authorities. With two of the remaining vessels being over 30 years old, vessel replacement and fleet rationalization became essential. Following an exhaustive investigation overseas, a 53 m, second-hand trawler with potential for modification for research, the *Ludovic Jego*, was purchased in France late in 1991, and is at present being rebuilt as a research ship. *Trachurus* will be disposed of in mid 1992. The rationalized research fleet will then consist of *Africana*, the refurbished *Ludovic Jego* (to be renamed) and the reliable workhorse *Sardinops*. Apart from the fleet, the Institute is supported by excellent services provided by the Research Engineering Service, the Library, the Reprographic section and the Data Processing group; which are often taken for granted. It would be difficult to better the services provided by these.

* * *

2. STUDIES ON RESOURCES

2.1 Demersal fish

FISHERIES worldwide are at the point where many of the available fish resources are being exploited close to, or even exceeding, their sustainable limits. One of the few areas in the ocean which have not been exploited fully and one in which research and exploitation become increasingly difficult with depth is the realm of the demersal or bottom fish. Demersal fisheries extend from the shallowest parts of the continental shelf to the deepest parts of the oceans. In South Africa the demersal fishery is the most valuable sector of the fishing industry in terms of product value. Demersal research therefore has a high priority and is directed primarily at assessing the health and exploitation capacity of the principal exploited stocks. These are the Cape hakes *Merluccius paradoxus* and *Merluccius capensis*, the Agulhas sole *Austroglossus pectoralis* and the kingklip *Genypterus capensis*.

Fish resources around South Africa depend on two very different hydrographic regimes. The cool Benguela system (West Coast) has a high productivity and low faunal diversity, whereas the warm Agulhas system (South Coast) has lower productivity but greater diversity. To accommodate the ever-changeable environmental conditions, demersal research is dynamic in its approach.

Much of the demersal research is carried out aboard F.R.S. *Africana*; in 1991, three surveys were conducted. Hake-directed biomass surveys were made in February (West Coast) and June (South Coast) and a survey directed at inshore species (sole, squid and horse mackerel) on the South Coast in September. All surveys applied the areal expansion technique (assuming uniform distribution over fixed depth strata) to obtain industry-independent estimates of biomass. The time-series of biomass estimates for hake now runs from 1983 on the West Coast and from 1986 on the South Coast (Fig. 3).

An innovative computer-based data-capture system has been developed that allows for immediate on-board capture of data. Species biomass and length frequency can be monitored continually as the surveys proceed and biological information is captured in an easy-to-access format for later processing. Development of this program is ongoing and upgrades currently being made include a facility to incorporate age readings with the length and biological data. The surveys are not totally directed at hake. The 1991 West Coast survey incorporated extra effort between the Orange River and Port Nolloth, where two experimental permits for the exploitation of the West Coast sole *Austroglossus microlepis* are operative. The data collected indicate that that stock remains depleted.

Stock assessment of the Agulhas sole remains problematic because survey estimates of biomass are considered to be biased (largely because of the relative inefficiency with which the standard trawling gear used captures benthic species such as sole) and because commercial catch rates are not considered a good index of biomass. Consequently, an ambitious research programme, which gathers information on the numbers of eggs produced during spawning to provide an estimate of the sole spawning biomass, is now at an advanced stage. For this study, sole have been captured in survey trawls, kept alive in holding tanks and successfully induced to spawn.

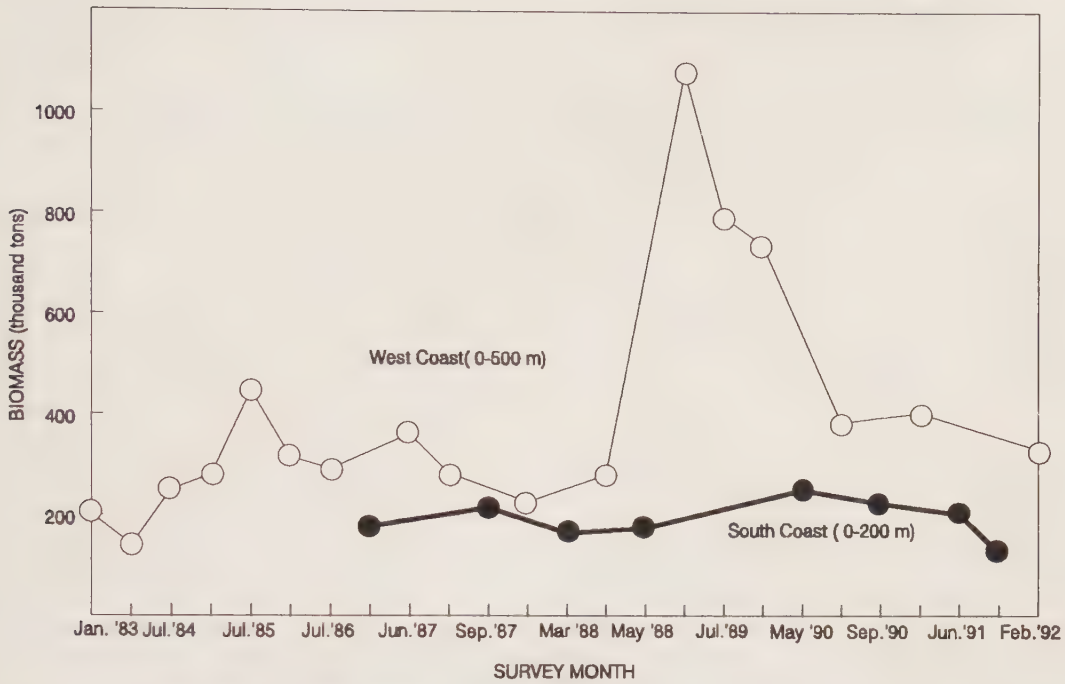

Fig. 3: Survey estimates of hake biomass off South Africa's west and south coasts, January 1983–February 1992

Demersal research holds great potential for integrated research. Close communication between biologists and environmental scientists are a feature of demersal research, and the results of environmental analyses are taken cognizance of in the assessment of particularly sole and squid, but also hake. Experimental transects, using both bottom and midwater nets, to investigate the diurnal, horizontal and vertical structure of generally demersal fish communities on the West and South coasts have also been initiated. The work will, it is hoped, lead to better understanding of the dynamics of demersal stocks and an increased ability to assess their status. Similarly, acoustic methods have been used on demersal surveys in an attempt to identify the biomass of, and to estimate the target-strengths of, juvenile hake. This too is an exciting prospect, because it has the potential to improve greatly upon the ability to assess and manage the valuable resource.

Improvements to the resource assessments and methods are ongoing. Present effort is being channelled towards, *inter alia*, reappraisal of sampling strategies, power factor analysis and towards refining, by means of liaison with the fishing industry, commercial perception of the policy for appropriate management. Results of the 1991 resource assessments show that the status of the hake stocks continued to improve, catch rates on both coasts being slightly higher than in 1990. The Total Allowable Catch (*TAC*) for 1991 was raised during the year to 141 000 tons.

Of major scientific concern in 1991 was the re-emergence of hake- and (to a lesser extent) kingklip-directed longlining, substantial catches of hake having been made outside of the recommended *TAC*. The effect this could have on the recovery of the hake stocks was

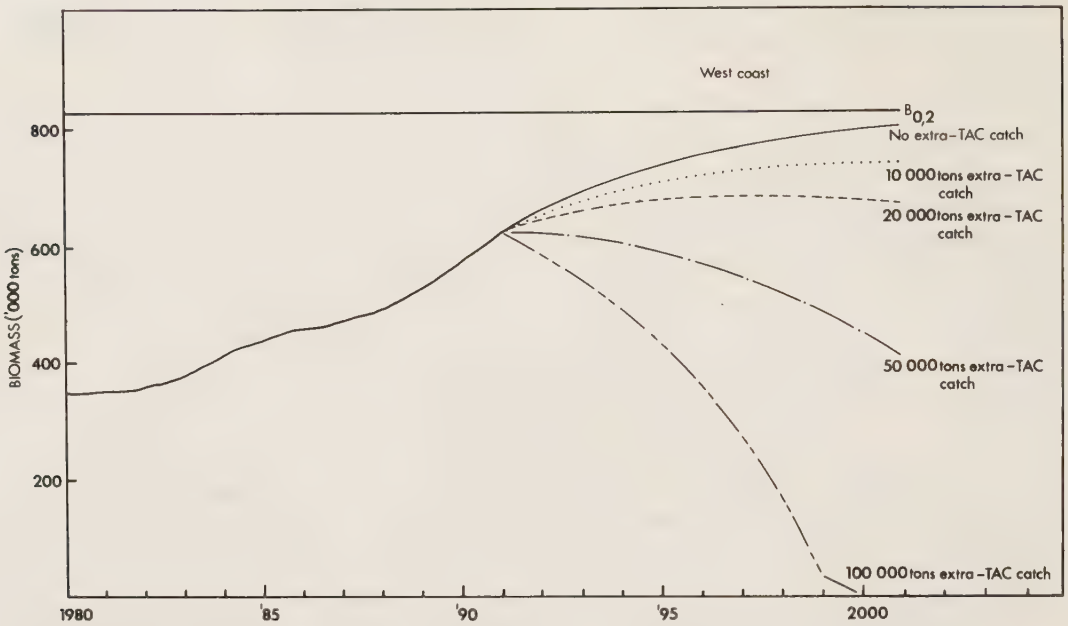

Fig. 4: Model estimates of the effect of catches over and above the recommended *TAC* for hake on the recovery of the hake resource off South Africa's west coast

modelled and, as is shown in Figure 4 (West Coast), at high levels it could have a serious impact on the resource. The levels of interaction between the traditional trawl fishery and a possible future longline fishery pose an interesting challenge for scientists and management. Future research on the impact of longlining will look closely at the selectivity patterns of the technique and compare this with trawl selectivity patterns. Kingklip research has been limited since the closure of the demersal longline fishery in 1990, although trawl catches and catch rates are still monitored closely. The stock remains heavily depleted, although kingklip catch rates in the hake-directed trawl fishery have shown some signs of improvement.

The proportion of hake in the total demersal landings has decreased recently (Fig. 5), an indication that by-catch species in the demersal fishery are assuming ever-greater importance. The increasing commercial importance of species such as monk *Lophius vomerinus*, gurnard *Chelidonichthys* spp., snoek *Thyrsites atun* and ribbonfish *Lepidopus caudatus*, shows that they will require greater research effort in future. Further, the introduction of a shark-directed longline fishery and the establishment of a fishery for gurnard in the St Helena Bay area highlights the need for research on species previously considered of little value.

Future demersal research, which will be vital to facilitating sound management decisions in the face of greater demands on fish resources in the fast-changing social and political environment, promises to be exciting. However, time, personnel and financial constraints will have to be addressed timeously, or crisis management will become the order of the day.

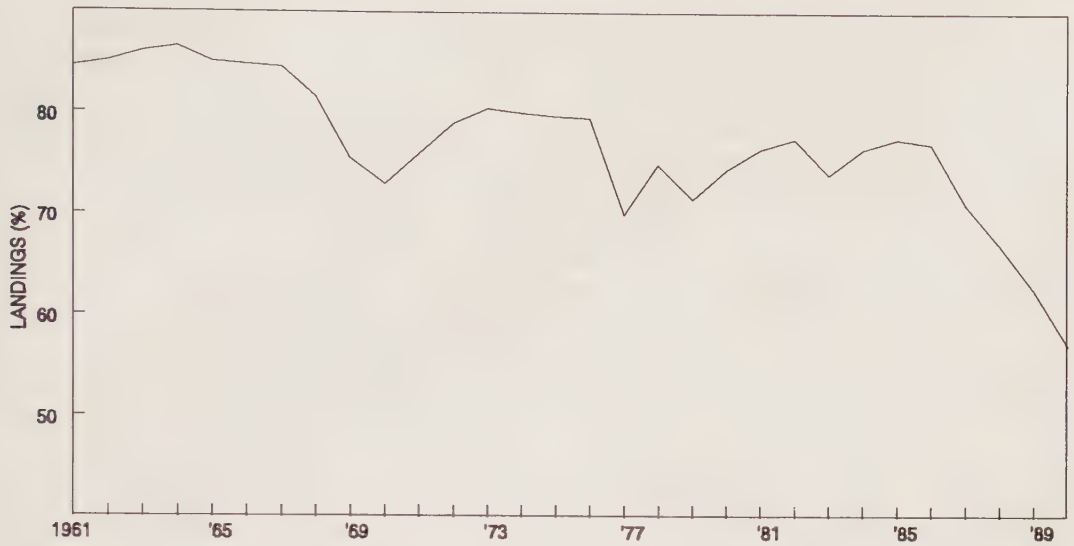

Fig. 5: The percentage contribution of Cape hake to the overall landings of South African demersal trawlers, 1961–1990

2.2 Horse mackerel

TRADITIONALLY, adult horse mackerel *Trachurus trachurus capensis* were caught by the South African demersal fleet as a by-catch in the hake- and sole-directed fisheries on the South Coast and as a directed catch by foreign (mainly Japanese) trawlers. However, development of local and export markets over the past few years has led to increased local interest in the resource. As a result, the South African demersal fleet is targeting for horse mackerel with greater frequency, there is less discarding and a midwater trawl fishery directed at horse mackerel has developed.

Since 1980 the total annual demersal landings have been fairly stable at between 25 000 and 36 000 tons, but this has been achieved by reducing the quota allocated to foreign interests as local demand has increased. The local fleet has, in fact, been allowed unrestricted catches. With continued increase in local demand and the development of the midwater trawl fishery, the local fleet now has the ability to exceed the maximum sustainable yield *MSY* for the resource; the 1990 catch exceeded what scientists would have recommended as *TAC* for that year. As a result, a scientifically based *TAC* for horse mackerel was introduced for the first time in 1991.

Stock assessment of horse mackerel is severely hampered by the lack of a high-quality, long-term data series and the fact that juveniles are taken as a by-catch in the pelagic fishery on the West Coast. At present, the Schaefer form of the Butterworth–Andrew surplus production model, extended to allow for multiple catch-rate series and biomass estimates from direct surveys, is used to assess the state of the adult resource. However, because of serious shortcomings in the time-series of catch and effort data from the local bottom-trawl fleet, this model is dependent upon the catch-per-unit-effort data provided by foreign fleets.

The feasibility of obtaining acoustic estimates of the biomass of horse mackerel on the South Coast was tested in October 1991. Horse mackerel appear to be ideally suited to

assessment by acoustic techniques and, provided the transects are run at night, acoustic assessment of the resource should be viable. A programme for annual acoustic assessment has been initiated. However, the accuracy of acoustic estimates of biomass is influenced by the accuracy of the estimated target strength for the species. Therefore, a program to estimate acoustic target strength *in situ*, using split-beam technology, was developed and tested during October 1991. The results indicated that the program works and that horse mackerel are suited to *in situ* estimation of target strength. The latter opens up exciting possibilities, because a literature search has failed to reveal any successful studies of the same nature on any other species of horse mackerel around the world. Further work to improve the accuracy of the estimated target strength will be carried out during future acoustic surveys. Also, a study of the vertical migration and behaviour of horse mackerel, that will also aid in improving the accuracy of the acoustic estimates of biomass, is in the planning stage.

Work on age determination of horse mackerel was recommenced after some years' gap towards the end of 1991. It is hoped that an age key for horse mackerel will be available by mid 1992, permitting the development of an age-structured assessment model for the species. However, because the historical annual estimated catch-per-length-class has been inadequate for some years, application of an age-structured model to the species in the near future could be severely hampered.

2.3 Pelagic fish

THE anchovy population bounced back in 1991 after several bad years. The first signs of this were found when the mass of anchovy recruits during the May 1991 acoustic survey was estimated to be 332 000 tons, a substantial improvement over recruitment in 1989 and 1990.

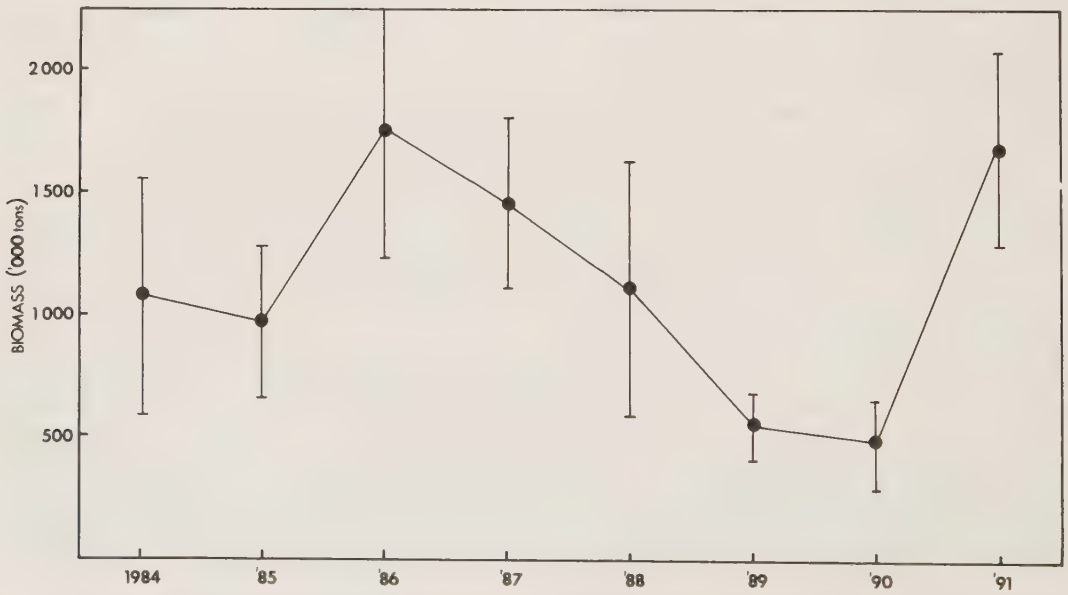

Fig. 6: Biomass of adult anchovy estimated from surveys conducted in November 1984–1991. Vertical bars indicate the 95% confidence intervals

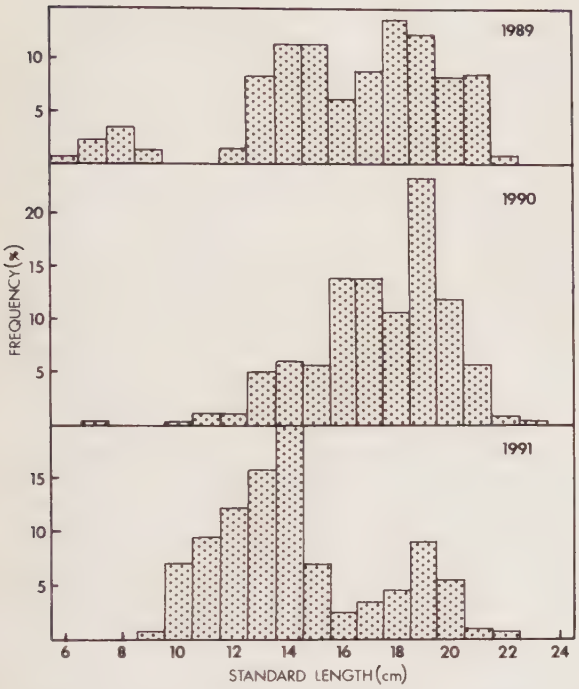

Fig. 7: Percentage frequency of occurrence of length-classes of pilchard caught in trawls in surveys conducted in November 1989–1991, weighted according to the acoustic density of fish on the surveys

In November 1991, the spawner biomass of anchovy was 1 682 000 tons, even higher than had been expected after the May survey and the second highest biomass recorded since acoustic surveys began in 1984. As this very high biomass followed the lowest spawner biomass on record, that of November 1990 (Fig. 6), it indicated that recruitment during 1991 must have been extremely good.

Similarly, good recruitment was experienced in the pilchard *Sardinops ocellatus* population, and the biomass in November 1991 was estimated to be 441 000 tons, the highest acoustic estimate for the species yet obtained. A higher proportion of the pilchard population in 1991 consisted of fish <16 cm than in either 1989 or 1990 (Fig. 7), indicative of the improved recruitment in 1991.

The management procedure used to determine the *TAC* of anchovy has included a constant proportion strategy since the start of 1991. This procedure seems far better suited to the needs of the pelagic fishing industry and the country than the strategy of constant escapement used previously. With this procedure, the initial *TAC* for 1992 was set at 270 000 tons, a marked improvement over the 1991 catch of 150 000 tons.

The management procedure for pilchard incorporates a constant fishing mortality strategy, a strategy similar to that of constant proportion used in the anchovy assessment. In an attempt to encourage recovery of the stock further, the fishing mortality is kept at the average level experienced between 1987 and 1989, a period under which the population showed substantial growth. At such a level of fishing mortality, under favourable environmental conditions, the pilchard population would be anticipated to show further growth. Applying the procedure resulted in a pilchard *TAC* for 1992 of 45 000 tons. The fact that this was lower than the 50 000 tons set for 1991 is a consequence of the high contribution of 0-year-old fish to the abundance measured in November 1991. Pilchard 1 year of age and older make up the bulk of the catch, in contrast to the situation in the anchovy fishery where recruits (0 years) dominate, and therefore the full benefits of the good recruitment in 1991 will only be felt as these recruits grow over the next few years.

The development of the management procedures for anchovy and pilchard will continue in order to try to optimize management of these resources. This will require ongoing liaison with all those involved in the management and utilization of the resources. As an aid to this, an interactive management model for anchovy is being constructed under contract to the Institute to assist in informing such people of the features of the existing management

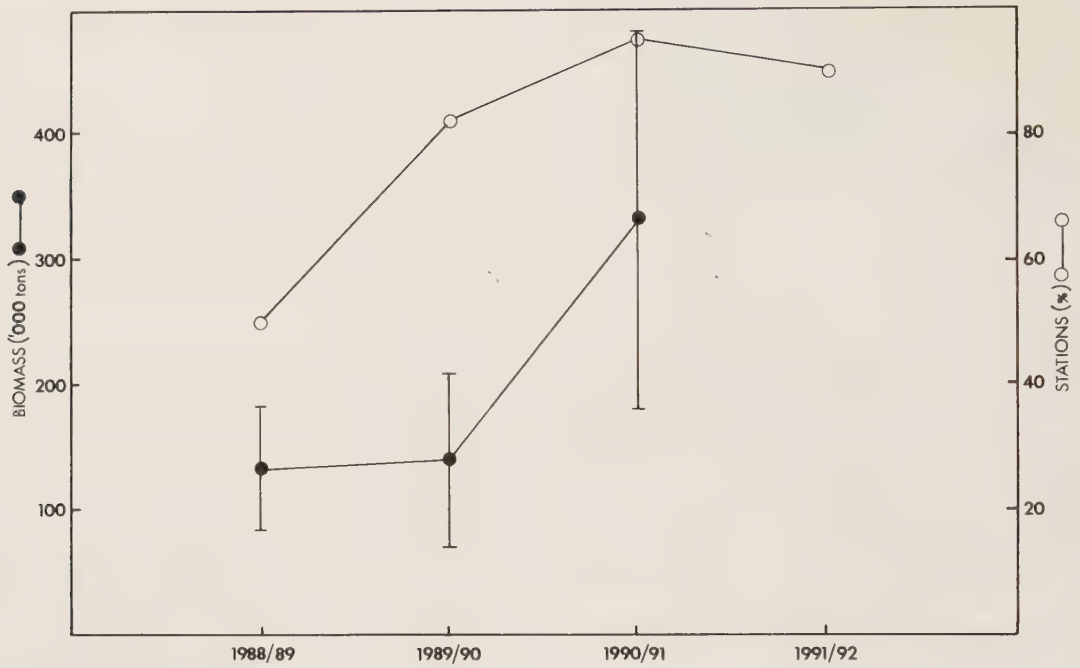

Fig. 8: Percentage of stations on the western Agulhas Bank on surveys in November at which copepod production was sufficiently high to meet basic ration requirements for the observed density of anchovy, and estimates of anchovy recruitment from the midyear acoustic surveys of the following year

procedure. It is also becoming necessary to look more closely at the potential size of the pilchard by-catch in the anchovy fishery and its relationship to both the anchovy and the pilchard *TAC*, in order to improve management of the latter. Developing the models necessary to do this will be a priority in the coming year.

Studies on the biology of pelagic fish continue to play a crucial role in the management of the commercial fisheries. Accurate determination of the age structure of the anchovy and pilchard populations and in commercial catches is essential to effective management. Therefore, efforts to improve the age-determination techniques were continued, and the latest techniques being developed are continually monitored and applied to local species when appropriate. Particular effort is now being put into improved sampling of catches at the field stations occupied during the season in order to ensure good estimates of the age structure of the annual pelagic catches.

Research into the reproductive biology of both anchovy and pilchard is also being continued, particularly relating to the application of the egg production method of biomass determination. The method is an important supplement to the acoustic method of estimating biomass and is applied routinely to anchovy. In addition, the necessary biological information is being collected for its application to determination of pilchard biomass. Problems have been experienced in the use of the method in recent years, and possible statistical solutions and improvements to the sampling technique are currently being investigated with urgency.

In anchovy, the recruits of a year account for an average of approximately 70% of the catch.

As a result of this, efficient management of the resource is hindered by the fact that, when the *TAC* is set in January of each year, the recruitment for that year cannot be estimated. Although the recruit survey is aimed at checking this recruitment and the *TAC* can be adjusted in the middle of the year, depending on the results of that survey, an early forecast of recruitment would assist management. Such prediction is one of the most elusive problems in fisheries biology, but some progress is being made in identifying important environmental influences and in obtaining early warning of, particularly, anchovy recruitment.

The feasibility of estimating pre-recruit strength in March each year by acoustic methods is being investigated and holds considerable promise. In addition, substantial effort is being put into studying environmental influences on anchovy and pilchard recruitment and into examining their influence on spatial distribution of each. Environmental researchers accompany the spawner biomass and recruit surveys and measure factors such as sea temperatures, strength and direction of currents, size, abundance and production of phytoplankton and the abundance and production of the different species of copepods fed on by both anchovy and pilchard. Although the data series is still very short, some interesting patterns are emerging. For example, the poor recruitment of 1988/89 was associated with low production of mesozooplankton on the western Agulhas Bank, whereas the very good recruitment of 1990/91 was associated with high production of mesozooplankton (Fig. 8). The role of such other factors as the consumption of anchovy eggs by pilchard, the extent to

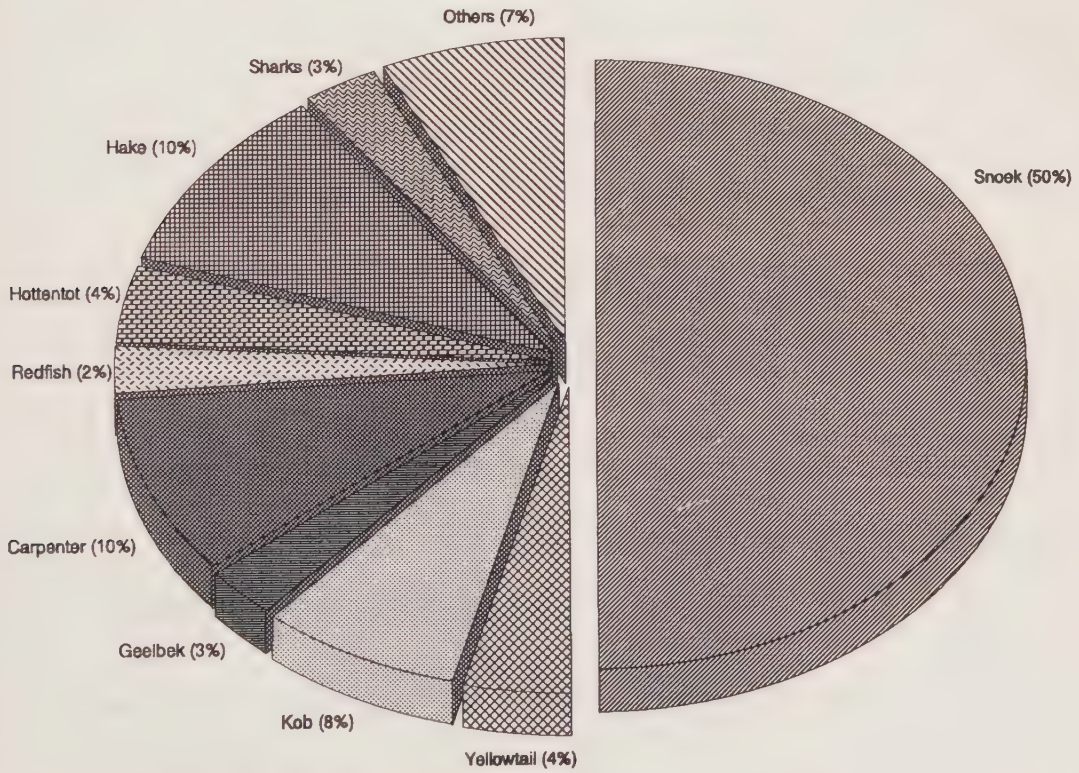

Fig. 9: Percentage contribution of different species to the commercial linefish catch of 1991

which Agulhas rings draw anchovy larvae away from the continental shelf and the distribution, size and concentration of phytoplankton particles in the Benguela system are also being investigated.

In the short- to medium-term, additional cruises during the spawning season are planned with the aim of studying changes in recruitment success and in environmental conditions within each spawning season. Such work will, it is hoped, provide additional information on regulation of this critical process.

2.4 Linefish

SINCE its inception in 1985, the National Marine Linefish System (NMLS) has developed into a powerful catch-and-effort database for linefish. It is being used in all aspects of management of the linefishery. During 1991, 2 792 commercial linefishing vessels reported 93 170 days fished and a total catch of 12 660 tons of linefish. Despite a 23% decline, the snoek catch remained good and contributed 50% of the linefish catch (Fig. 9). Catches of kob *Argyrosomus* spp. decreased markedly, whereas those of red steenbras *Petrus rupestris*, chub mackerel *Scomber japonicus* and elf *Pomatomus saltatrix* increased (Fig. 10).

The NMLS was particularly useful in monitoring the controversial longline fishery for hake that developed after the issue of shark and tuna longline permits in 1991. A number of larger linefish vessels used longlines or modified handlines to make highly profitable catches of large hake as well as a substantial by-catch of kingklip. Clearly, the total longlined catch of hake markedly exceeded the reported 1 260 tons. Concern for the future of the hake and kingklip stocks resulted in legislation to control line catches of these species in early 1992.

Under a research contract with the Institute, the Oceanographic Research Institute in Natal captured 24 320 recreational daily catch records from shore and boat anglers and 5 703 shore-patrol cards from the Natal Parks Board. These data provide a scientific index of the

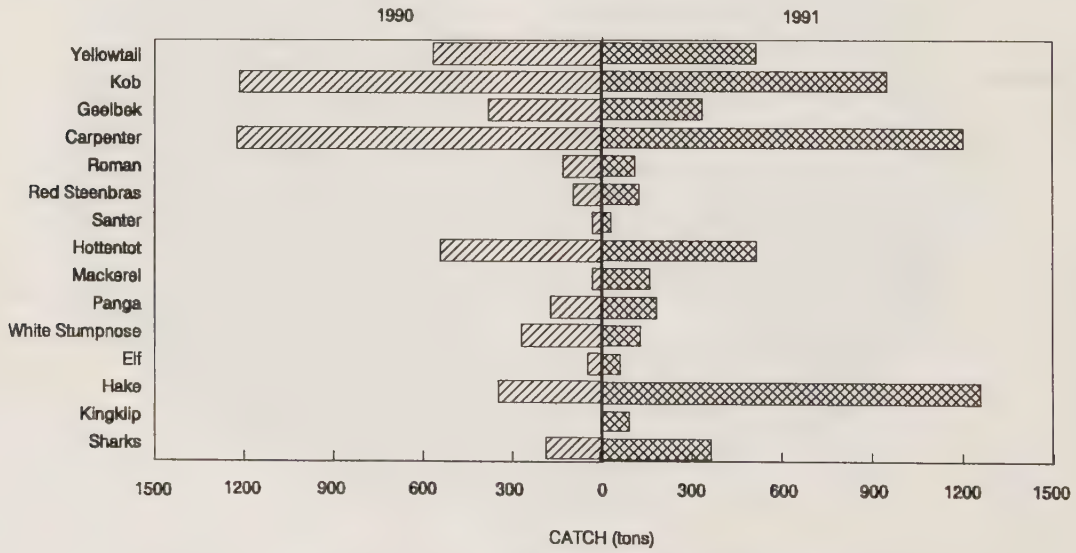

Fig. 10: Commercial catches of selected species of linefish in 1990 and 1991

recreational linefishery in Natal and will be used, together with commercial data, to extensively revise linefish management measures, particularly species categories and bag limits, during 1992.

Sampling of fish to determine size at maturity as a scientific basis for the establishment of effective minimum size limits continued, effort being concentrated on the white stumpnose *Rhabdosargus globiceps*. Catches of this species increased rapidly in False Bay between 1985 and 1990 and, as a result of the inadequate size limit of 20 cm (±130 g), two-thirds of the landed fish were below the size at 50% maturity of 30 cm (±425 g). An initial recommendation of 30 cm was later revised to 25 cm fork length (±250 g) after representations from some commercial fishermen.

Research contracts with other organizations provided valuable information on the biology and stock status of other important linefish species around the coast. Scientists at Rhodes University ascertained that South African kob catches consist of two species which cannot easily be distinguished. The larger, inshore species is caught primarily by fishermen from shore and in small boats, particularly in the Eastern Cape and Natal. The smaller, offshore species forms the bulk of kob catches by offshore linefishing boats and trawlers farther west. The two species have markedly different growth rates and sizes at maturity, presenting a challenge for development of effective management measures for kob in the near future.

A contract with the University of Cape Town to investigate the biology and stock status of white steenbras *Lithognathus lithognathus* ended at the end of 1991. This species is the most important for shore angling in the South-West Cape, and the study was initiated in response to fears that beach-seining in False Bay was depleting the stock. Results clearly show overexploitation, by both recreational fishermen from shore as well as by beach-seine. Various management proposals, including increase in the minimum size, area closures and catch reductions, will be evaluated during 1992. A detailed study of other aspects of the False Bay beach-seine fishery is being conducted under further contract research designed to conclude in 1993.

Contracted researchers at the Oceanographic Research Institute in Durban are investigating the biology and stock status of a number of important linefish species off Natal. Intensive research on sex-change and migration in the slinger *Chrysoblephus puniceus*, commercially the most important linefish species in Natal, has provided insight into how, despite heavy exploitation of the larger males off Natal, catches are being sustained by influx of fish from the adult stock off Moçambique. Further, investigation of discarded by-catches from the Natal inshore prawn-trawl fishery has provided the first quantitative information on by-catch species of fish in that fishery. Results show that, although juvenile sciaenids make up 85% of the discarded catch, most species trawled are not targeted by linefishermen, and competition between the fisheries is limited mainly to the snapper kob *Otolithes ruber*. Work on recreationally important gamefish species, such as king mackerel *Scomberomorus commerson*, queen mackerel *S. plurilineatus* and kingfish *Caranx* spp., is due to be completed soon.

A number of intensive research projects on the extent to which marine reserves protect linefish species are now providing interesting results. Fish census, tagging and evaluations of catch rate in the De Hoop Marine Reserve continued with a number of research cruises. In all, 7 815 fish have been tagged to date, and 554 have been recaptured. Results have confirmed

the strong residency of Roman *Chrysoblephus laticeps* and rockcods *Epinephelus* spp., but additionally have provided unexpected evidence of equally strong residency for the juveniles of species previously considered to be highly migrant, particularly the red steenbras. Whereas adult red steenbras migrate between the Agulhas Bank and spawning areas off Transkei, juveniles remain resident in recruitment areas in the Southern Cape, where they are exposed to heavy exploitation by linefishermen. This species could therefore benefit from adequately large marine reserves in the recruitment areas. This marine reserve work is being complemented by contracted research on the Tsitsikamma National Park, being conducted by Rhodes University.

2.5 Squid

THE squid-jigging industry has gone from strength to strength since its inception in 1985, the commercial value of the squid resource growing to over 10% of the total for all sectors in 1989. This has been reflected in increased activities of the squid research team, which has drawn several new researchers into a cohesive, productive and goal-orientated research programme. The overall aims include the development of a management strategy for the chokka squid *Loligo vulgaris reynaudii* resource, improvement of biological knowledge of the species and an attempt to link abundance and distribution to environmental parameters on a range of spatial and temporal scales.

An important aspect of the management of this resource is the development of stock assessment methods. So-called Leslie-DeLury models can be applied to describe the effect of exploitation on squid stocks by means of catch-per-unit-effort data. Other models and data are to be evaluated with the aim of developing a model specifically for loliginid squid stocks which, it is hoped, can be used as a management tool. Survey methods of assessing the squid resource are also being investigated. Acoustics hold the promise of a successful new approach. Two pilot surveys have shown that spawning biomass can probably be measured during the peak spawning season when large aggregations occur in bays.

Understanding the life cycle of chokka squid has been hampered by an inability to age squid. A project to investigate growth rings in chokka squid statoliths by means of light and scanning electron microscopy (Fig. 11) will gain momentum in 1992. South Africa is in the forefront of research in this field; a textbook on squid ageing by means of statoliths was recently published in collaboration with scientists from Japan and Canada.

In developing knowledge of the life cycle and reproduction of chokka squid, several studies have heightened understanding of feeding, shoaling and reproductive behaviour, aspects vital to understanding the mechanisms that affect recruitment. The use of a remotely operated vehicle has enabled direct observations of spawning and mating squid to be made in the vicinity of egg beds.

An integral part of the research programme is a suite of three environmental projects. The first of these is aimed at understanding the large-scale oceanography of the South Coast shelf. Information is collected by means of regular shelf transects and moored instrument arrays in bays used by spawning squid. The second investigates, by means of laboratory and field experiments, the influence of the environment on squid eggs and hatching. The spawning habitat of squid will be studied in a third project. The last two projects are the first of their kind aimed at squid.

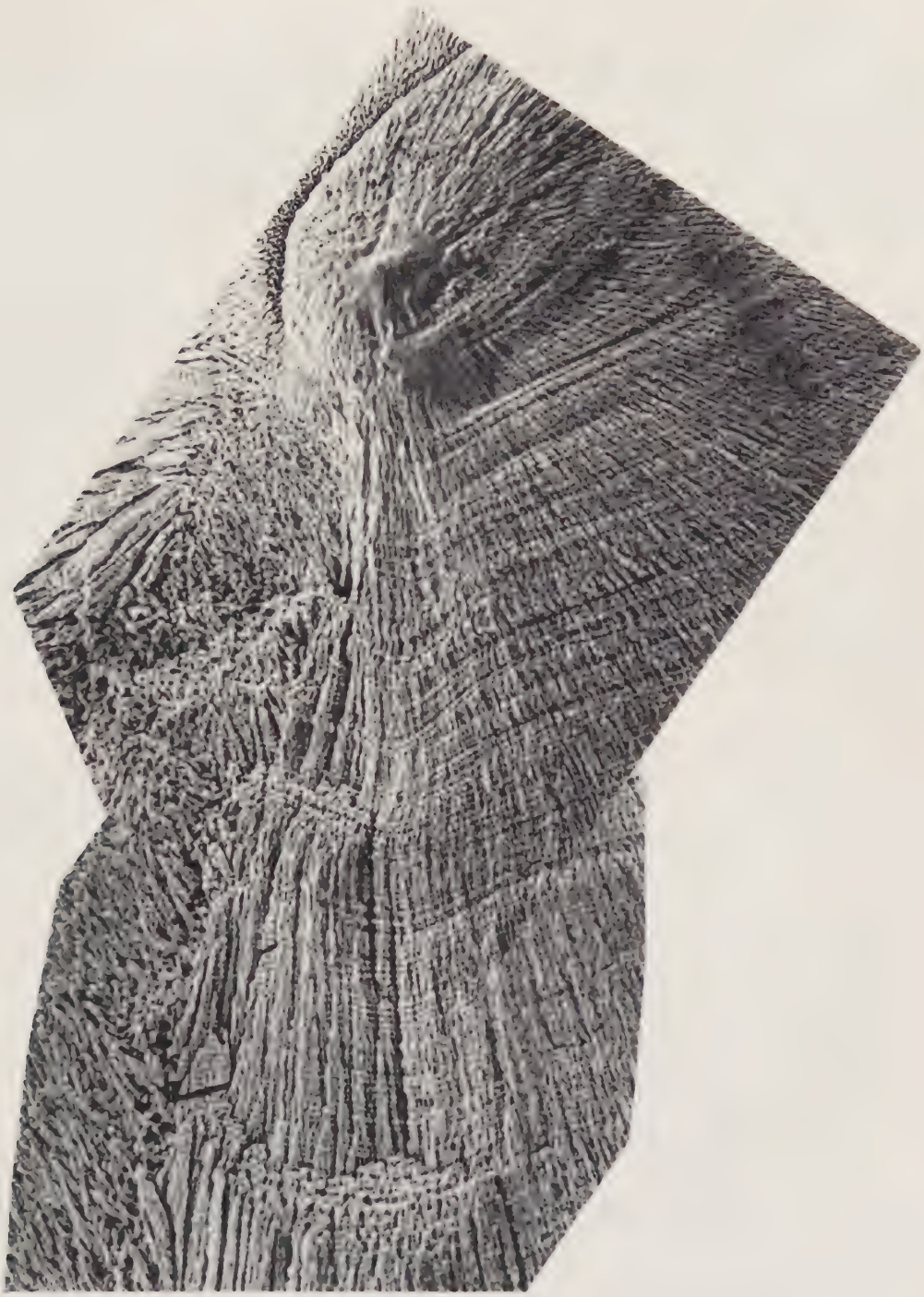

Fig. 11: A scanning-electron micrograph showing daily growth increments on the statolith of a chokka squid

2.6 Abalone

THE commercial abalone *Haliotis midae* fishery has been in existence since the 1950s. In early days of the fishery catch rates were high, as divers "mined" large accumulations of the species. However, since then it has developed into a quota-controlled fishery with Total Allowable Catches (*TAC*s) set each year for discrete fishing grounds. Monitoring of catch rates and the size composition of the commercial catch remains an important indicator of the status of the resource, and results show that the fishery has reached a period of stability since the mid 1980s.

A vital aspect of resource sustainability centres around annual recruitment success. In recent years, recruitment studies, during which divers investigate the abundance of recently settled abalone at four sites, have shown that Robben Island only receives intermittent settlement. The other three sites, all east of Cape Hangklip, receive regular annual settlements (Fig. 12). This finding may explain why commercial fishing has stopped on the West Coast, except off Robben Island, where past accumulations still exist.

A new direction for research which is showing meaningful results is the use of a telephone survey to poll recreational abalone sport-divers, and so to estimate their annual take. Final results for 1991/92 are not yet available, but indications are that the impact of the sport diver on the resource is *far* higher than previously thought, with a take of probably more than 200 tons per annum. This is a significant quantity, because the commercial fishery had a 600 ton *TAC* for 1991/92. Research aimed at quantifying the impact of this sector on the fishery will be a high priority in the future, in order that informed decisions can be made on the future of the sport fishery.

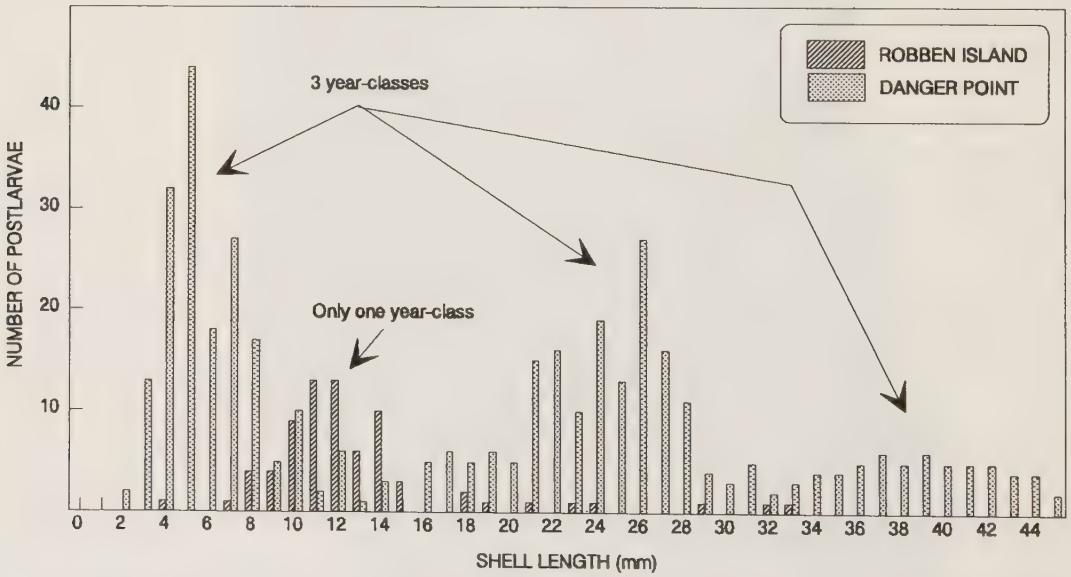

Fig. 12: Numbers of abalone with a shell length <45 mm encountered on surveys at Danger Point and Robben Island, illustrating the regular settlement of year-classes at Danger Point but sporadic recruitment at Robben Island

2.7 Rock lobster

CATCH rates of West Coast rock lobster in the 1990/91 season were the worst on record. The season finished with a final catch of 2 996 tons, some 21% short of the *TAC*. The reason for the poor performance by the fishery was that growth rates of rock lobsters in all areas off western South Africa for which comparative growth data are available were extremely low. Retarded growth resulted in fewer rock lobsters than normal recruiting to the fishery and this, in turn, impacted negatively on catch rates and therefore on the economic potential of the fishery.

Reasons for the slow growth rate of rock lobsters are not fully understood. Benthic diving surveys undertaken at Elands Bay in December 1990 and at Dassen Island in February 1991 showed reduced quantities of mussels, compared to similar surveys in the late 1970s and early 1980s. As mussels form an important component of the diet of the West Coast rock lobster, it is conceivable that the apparent decline in the mussel population could have affected productivity of rock lobsters. However, further research will be required to clarify the relationship. Possible direct links between the environment and periods of slow growth rate of rock lobsters are being explored by examining records of swell height, and by collection of appropriate data on temperature and dissolved oxygen.

During 1991, much effort was put into contributing to and reviewing scientific recommendations for management of the rock-lobster resources. The role of sanctuaries for conservation of rock lobsters was explored, and it was concluded that all existing rock-lobster sanctuaries, with the exception of Robben Island, served a useful purpose and should be retained. At Robben Island, commercial fishing on a small scale (a 50 ton *TAC*) was reinstated in the 1991/92 season.

Researchers see some of the remaining rock-lobster sanctuary areas as "field laboratories". Scientific studies frequently draw attention to the potentially confusing effects that commercial fishing can have on certain research conclusions. One of the benefits of retaining some sanctuaries is that scientists can use such unfished areas as living examples of what the West Coast inshore rock-lobster fishing grounds may have looked like prior to commercial harvesting. In this way, understanding of the fished populations can be improved.

Recent research has focused on whether there is scientific justification for a reduction in the minimum legal size for West Coast rock lobster. In 1991, scientific consultants to the fishing industry submitted a proposal for reducing the minimum size from the existing limit of 89 mm. A minimum size of 65 mm or of one between 65 and 89 mm was mooted. Proper interpretation of model results necessitated examination of, and scientific debate on, several related issues, including rates of natural mortality, the extent that egg production might be affected by a size reduction and the impact of discard mortality (the mortality of undersized rock lobsters returned to the sea during the course of commercial fishing). Investigation of the ramifications of different size limits will continue in 1992.

In 1991/92, for the first time, catches made by recreational fishermen were monitored by means of a telephone survey. The survey will, *inter alia*, supply information on catches made in different areas and by different fishing methods. It is believed that this information will make an important contribution to future management decisions.

A project which utilizes brood sizes of females to predict male growth increments is being

used with considerable success, and it will be possible to use this predictive index with more confidence as the data base expands each year. The project was broadened recently to include biochemical changes in the hepatopancreas of male rock lobsters as a possible predictor of growth. The hepatopancreas of rock lobsters is the storehouse of lipid, protein and carbohydrates, all of which are directed into growth during the annual moult. The thinking behind this new project is that it may be possible to analyse the accumulation of these biochemical products prior to the moult, and in this way to predict the likely moult increment. It is essential to have an indication of growth before setting a *TAC*; the overoptimistic *TAC* set for 1991/92 is proof of just how essential it is for researchers to have the type of information that this project might be expected to yield.

The South Coast rock lobster *Palinurus gilchristi* fishery has apparently remained relatively stable over the past decade, both in terms of catch rate and *TAC*. Tagging of South Coast rock lobsters has continued, with the goal of obtaining information on growth and migration of the species. Results have shown that the species is capable of extensive migration and that its growth rate is faster than was formerly believed to be the case. However, both growth rates and patterns of migration have varied with area of release of animals. More information is needed if data collected to date are to be interpreted with confidence.

2.8 Seaweed

KELPS (large brown seaweeds) provide alginic acid, an essential ingredient in many modern industries. South Africa's west coast supports in the order of a million tons of kelps, but it has become necessary to obtain firmer estimates of biomass. In 1991, the fresh biomass of kelps

Fig. 13: Lanes cropped through the kelp forest at Soetwater stand out clearly

Fig. 14: A bundle of *Gracilaria verrucosa* healthily growing from transplants pegged into the sandy floor of Saldanha Bay (a) at transplant; (b) one month later

accessible at Port Nolloth over an area of 139,1 ha was estimated to be 26 000 tons. Estimates of biomass at other areas are to be undertaken.

The ecological impact of harvesting kelps at Soetwater, Kommetjie, on the southern Cape Peninsula (Fig. 13) appears insignificant. However, monitoring will continue. Product of the kelp harvest is used to promote healthy growth of agricultural crops.

Research near Port Elizabeth on the effect of harvesting *Gelidium pristoides*, an agar-producing red seaweed, was terminated early in 1991 after it had been demonstrated that the harvests did not affect the ecological balance of the community. Monitoring had been undertaken every three months for a period of nearly four years.

Another producer of agar is *Gracilaria verrucosa*. Abundant beachcasts formerly supported a flourishing industry at Saldanha Bay, but they almost disappeared during the late 1970s. There were signs of recovery in the 1980s, but at the end of 1989 the species suddenly vanished from the area. Subsequent observations indicated that the collapse may have been caused by herbivores. In 1991, successful transplants to Saldanha Bay were made from nearby Langebaan Lagoon (Fig. 14) and bode well for resuscitation of the crop.

In 1991, ecological studies were also conducted on *Hypnea spicifera*, a jelly-forming red seaweed (Fig. 15).

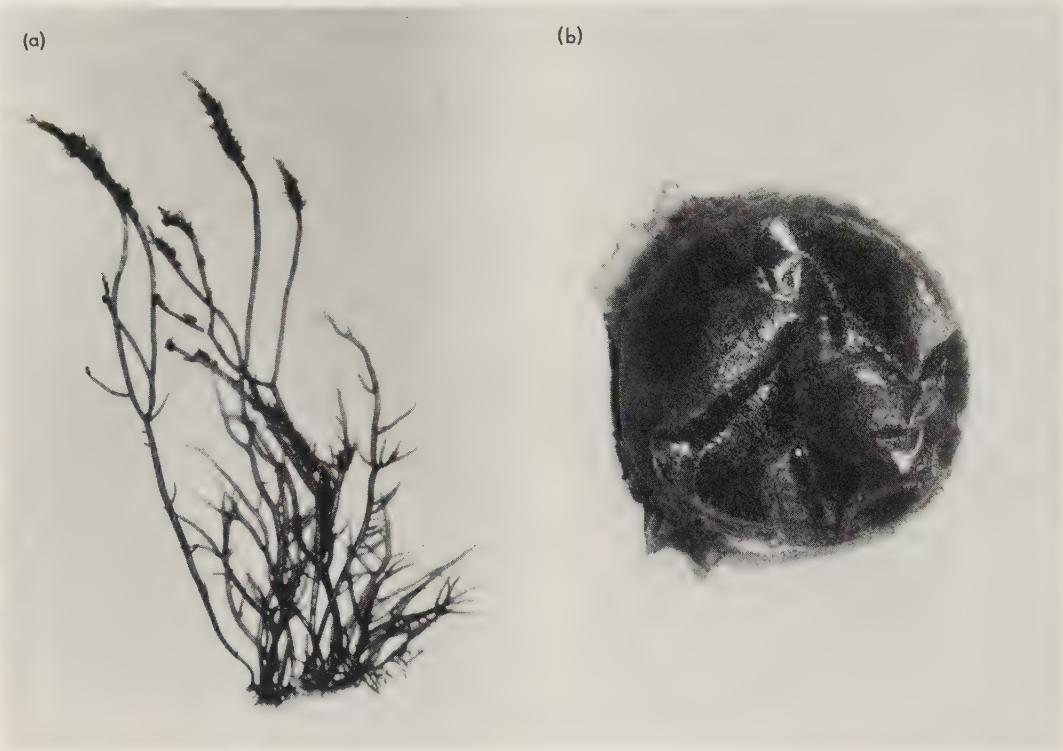

Fig. 15: Strands of *Hypnea spicifera* (a) of which boiling water extract forms a firm jelly (b) at ambient temperatures

* * *

3. ECOLOGICAL STUDIES

3.1 Marine ecosystems

CONSERVATION of marine ecosystems and optimal utilization of resources are twin objectives of South Africa's Sea Fishery Act of 1988. At present, advice on the management of resources is based on single-species approaches, and the impact that exploitation of resources may have on other components of the ecosystem, for example on predators of the exploited resources, is not explicitly accounted for. This has resulted partly from a lack of information with which to model relationships between prey and their predators. Improved time-series of empirical information may permit construction of such models.

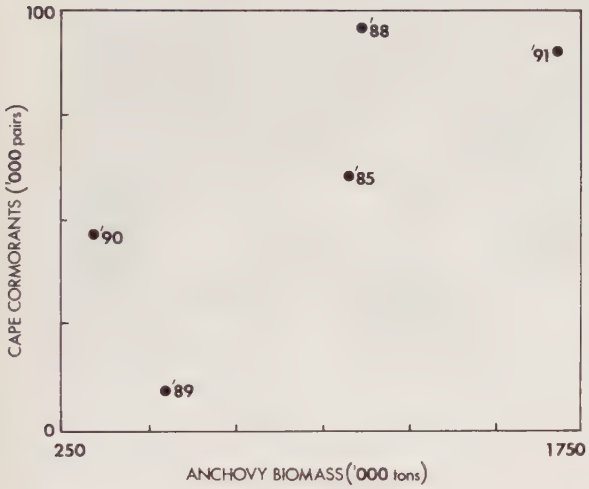

Fig. 16: Relationship between numbers of pairs of Cape cormorants nesting off western South Africa in the austral spring and the biomass of adult anchovy measured on surveys in November of 1985 and 1988–1991. Surveys of Cape cormorants were not conducted in 1986 and 1987

For example, preliminary results suggest that numbers of Cape cormorants *Phalacrocorax capensis* breeding in any one year are related to the biomass of anchovy (Fig. 16). A prototype model linking Cape cormorants to the anchovy resource was developed to explore how different management strategies for anchovy might impact the cormorants. Relationships used predicted roughly equivalent numbers of Cape cormorants for certain exploitation strategies that generated different mean catches. This suggests that careful selection of a management strategy for a prey species may allow higher yields without compromising the conservation status of predators. It remains uncertain that all predators will respond in the same manner as Cape cormorants, so further modelling considering other predators is clearly necessary.

3.2 Seabirds

ANCHOVY are important in the diets of four species of seabird breeding in South Africa — African penguin *Spheniscus demersus*, Cape gannet *Morus capensis*, Cape cormorant and swift tern *Sterna bergii*. The recent large fluctuations in the biomass of anchovy off South Africa have provided an excellent opportunity to study responses of these seabirds to altered availability of anchovy. The information will be useful in assessing impacts that various management strategies for anchovy may have on seabird populations.

The swift tern (Fig. 17) provides an example. Spawning anchovy were abundant in November 1986, but thereafter decreased steadily to low biomasses in the Novembers of 1989 and 1990. Numbers of swift terns breeding off western South Africa the following autumn matched this trend closely (Fig. 18). In 1991, there was a large increase in the

Fig. 17: A swift tern returning to a breeding colony at Jutten Island carrying an anchovy in its bill

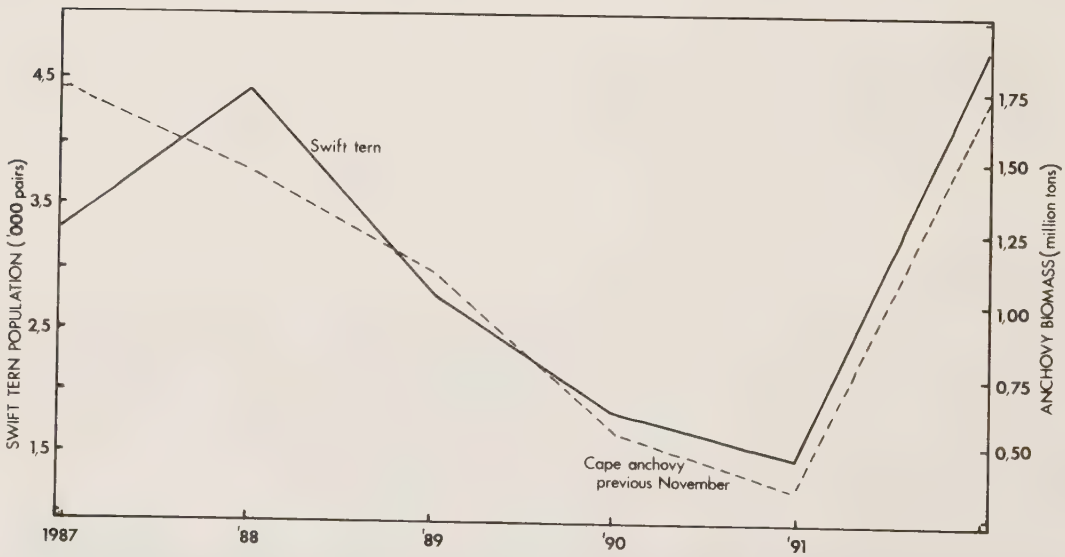

Fig. 18: Relationship between numbers of pairs of swift terns nesting off western South Africa in the austral autumn and the biomass of adult anchovy measured on surveys in the previous November

biomass of spawning anchovy, followed in the austral autumn of 1992 by a strong recovery in the number of swift terns breeding.

It is evident that large numbers of mature swift terns chose not to breed off western South Africa when anchovy were scarce. There were similar responses by African penguins, notably at the populous colony of Dyer Island, Cape cormorants and, to a lesser extent, Cape gannets to the low abundance of anchovy.

3.3 Marine mammals

WHEREAS the conservation status of some of South Africa's seabirds gives cause for concern, and some seabirds may be adversely influenced by commercial fishing of prey species, the recovery during the 20th century of the South African fur seal *Arctocephalus pusillus pusillus*, after three centuries of overexploitation, is one of conservation's success stories. One negative consequence of this is that the impact of a large seal population on resources of commercial fish *may* be considerable. A workshop investigating this aspect was held under the auspices of the Benguela Ecology Programme during September 1991. More than 20 scientists from 11 countries participated. The workshop concluded that explicit multispecies models were probably the most appropriate means of examining the effects of consumption of fish by seals on catch rates and catches of the fisheries.

A proper understanding of the diet of seals and other major predators is an important prerequisite for development of such models. The workshop concluded that the relative mass of undigested remains of different prey categories (e.g. teleost fish, cephalopods, crustaceans) in seal stomachs would be a better index of their importance in the diet than the frequency-of-occurrence method used formerly. Accordingly, the contribution of prey items to the diet was recalculated for samples collected during the period 1988–1990. The revised method considerably reduced the estimated contribution to the diet of uncommon prey items,

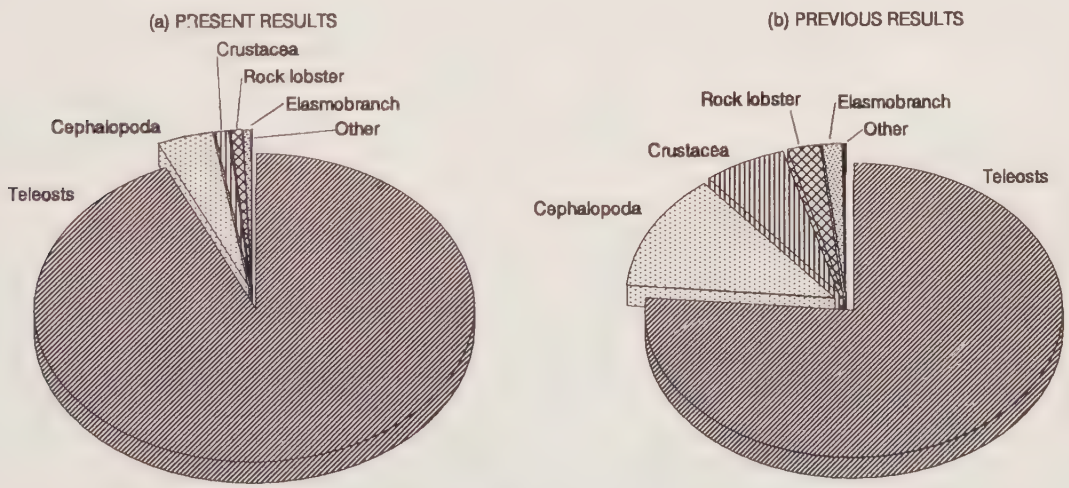

Fig. 19: Estimated contribution of prey categories to the diet of South African fur seals, (a) by mass of undigested remains and (b) by frequency of occurrence of prey items. The former method is considered more reliable and considerably reduces the importance of less frequent prey items such as cephalopods and rock lobsters

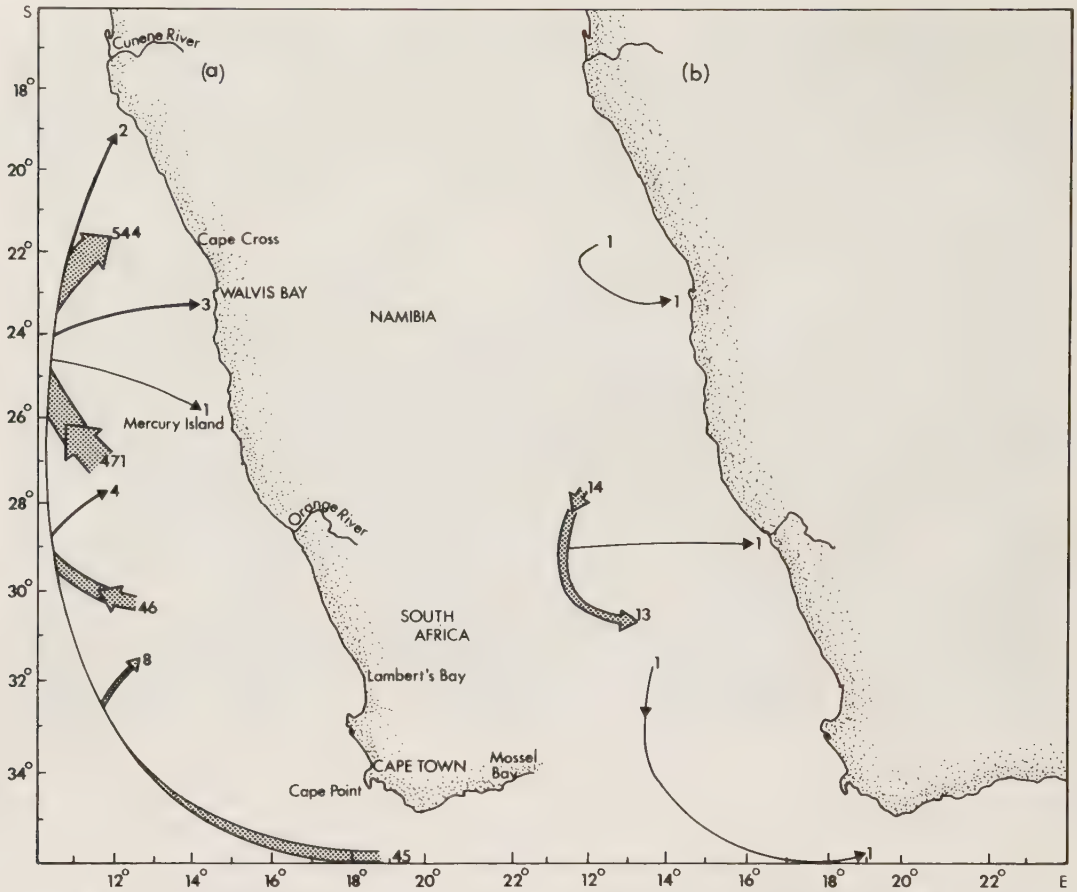

Fig. 20: Southerly and northerly movements recorded for tagged South African fur seals, illustrating the considerable interchange of animals between different areas

such as squid and rock lobster (Fig. 19). This is an important conclusion, because the earlier method showed apparently very high consumption of squid and rock lobster by seals, so giving the mistaken impression that survival of those fisheries was threatened by the burgeoning seal population.

The long-term tagging programme, during which more than 75 000 seal pups have been tagged since 1971, has yielded interesting results. Analysis of recoveries shows that the Namibian and South African seal populations are effectively one stock. Seals, particularly juveniles, may move around the coast from colony to colony (Fig. 20). The focal point of these movements is Cape Cross in Namibia. Seals from most other colonies, including those from as far distant as Cape Agulhas, were recovered there. Another conclusion which supports the idea of there being a single seal stock is that seals from different colonies share the same feeding grounds. Two feeding grounds stand out as being of major importance, the area north of Cape Cross and that between Cape Point and Cape Columbine.

Research plans for 1992/93 include the implementation of an exciting new idea for improving the quality of information obtained from the seal collecting cruises, through identi-

fication of the species and biomass of prey in the vicinity of collected seals. This will involve following the cruise track of F.R.S. *Africana* so that advantage can be taken of her hydro-acoustic capability in identifying fish shoals. Another ongoing project is that of monitoring pup mortality from birth through to weaning at about nine months of age at the Kleinsee colony. Pup mortality is a vital parameter in the population model. Finally, population age structure is being determined by examination of thin sections of canine teeth of a large sample of individuals. Age structure, too, is important in the population model.

3.4 Environmental monitoring

SOUTH AFRICA'S marine environment is characterized by great interannual variability. This fact, coupled with knowledge of possible global climate change, necessitates long-term observation of the environment so that gradually occurring climate-related changes may be detected and shorter term observations placed in their correct temporal perspective. The Institute's environmental monitoring programme includes collection, analysis and interpretation of important environmental data relevant to southern Africa. These data allow identification and detailed description of environmental perturbations, such as that shown in Figure 21, the monthly equatorward wind components for the South-Western Cape being generally below average for 12 months. This suggests a reduction in coastal upwelling then as well as other implications, which will be incorporated into resource assessments through computerized expert systems being developed for the purpose.

Environmental research efforts are coordinated with biological studies so as to optimize understanding of environmental/ biological interactions. The availability of more reliable time-series of biomass, recruitment and distribution of important biological resources now allows their meaningful comparison with environmental data. A publication dealing with environ-

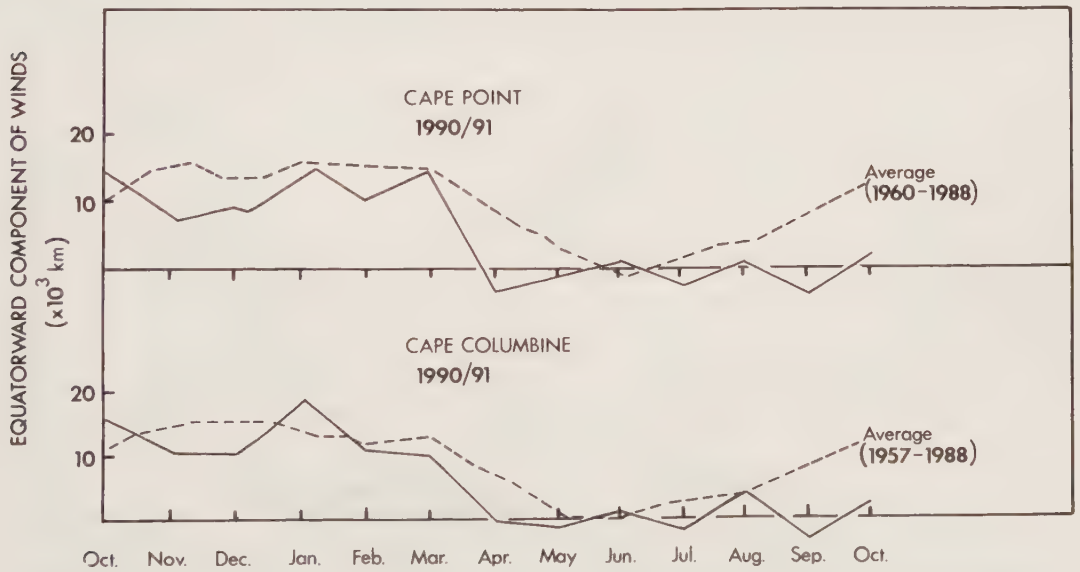

Fig. 21: The equatorward component of coastal winds at Cape Point and Cape Columbine, October 1990–October 1991, contrasted with long-term monthly averages

mental change and related resource variability in the Benguela system over the past decade is in press.

Two experiments aimed at understanding species-specific environmental/biological interactions have started. In July 1991, an oceanographic buoy was moored in St Francis Bay on the South Coast and a suite of physical parameters, including ocean currents, is being recorded automatically by undersea instrumentation. Biological experiments on chokka squid are being conducted simultaneously and should, in combination with the oceanographic data, provide greater understanding of the interactions between squid life history and their environment. Such knowledge is important as a tool for the optimal management and conservation of the resource. Another exciting development is the deployment of a continuously recording dissolved-oxygen probe at Elands Bay on the West Coast — work planned for July 1992. This region has seen events where rock lobsters have left the sea, apparently in an attempt to escape low levels of dissolved oxygen. This first-ever time-series of dissolved oxygen will greatly improve understanding of such events and the environmental conditions which presage them.

The Institute is also actively participating in such international ventures as the World Ocean Circulation Experiment (WOCE) and the Joint Global Ocean Flux Study (JGOFS). A small part of a 1992 deep-sea cruise on F.R.S. *Africana* was aimed at studies of pH and alkalinity. From this study, it is hoped to estimate the partial pressure of carbon dioxide dissolved in waters around South Africa and therefore the potential for uptake or release of the gas by the sea.

3.5 Global environmental change

SOUTHERN Africa's marine ecosystems and resources have been influenced substantially by past environmental change. For example, there have been alternating regimes of great abundance of pilchard or anchovy off the West Coast. Other world regions where sardine and anchovy are plentiful have also experienced shifts in dominance between these two species. Interestingly, the shifts have all occurred at more or less the same time, although the southern

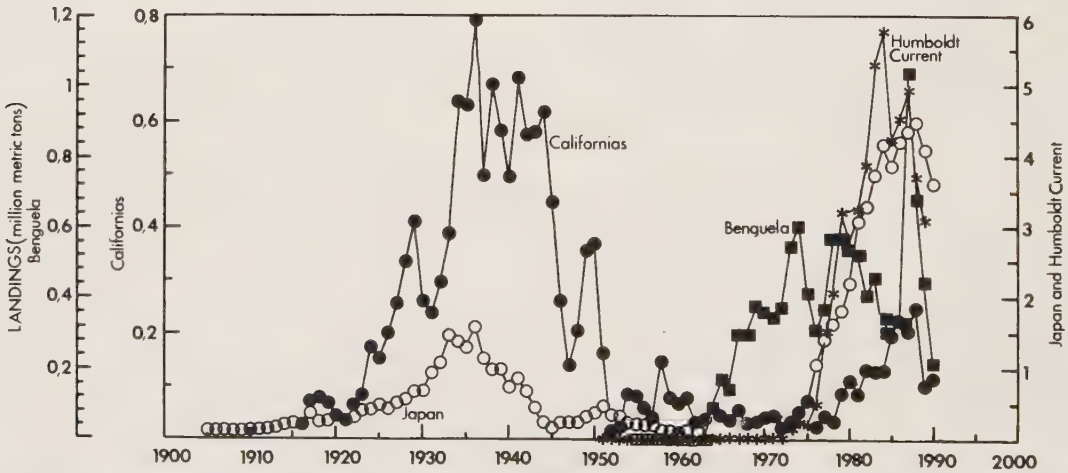

Fig. 22: Trends in the landings of anchovy in the Benguela system contrasted with landings of sardine in three well-separated regions of the Pacific Ocean (Japan, the Californias and the Humboldt Current), 1905–1990

African system has tended to be out of phase with those in the Pacific Ocean — anchovy dominating when sardine is abundant in the Pacific (Fig. 22) and vice versa. It is possible that the well-separated regions are being influenced by the same environmental mechanism. If this is the case, they are likely to be highly sensitive to global environmental change.

3.6 Marine pollution

BAYS are particularly vulnerable to pollution as a result of their relatively restricted circulation of water. At the same time, the relative shelter of their waters makes them ideal sites for harbours and for recreation and mariculture operations. This statement is clearly reflected in the distribution of coastal towns and cities in South Africa.

It is for this reason that much research over the past few years has been focused on Saldanha Bay, which is a deep-water port, a shellfish farming centre and a recreational paradise. The project aims to provide an understanding of the factors which regulate the ecology of the Bay and how this is being modified by anthropogenic influences. It includes three main areas of research: physical, biogeochemical and biological. Ultimately, the information should provide a sound basis for future management of Saldanha Bay.

Results obtained over the past year suggest that, although gross effects on benthic communities are limited to the sea area within 100 m of the outflow from the fish factories,

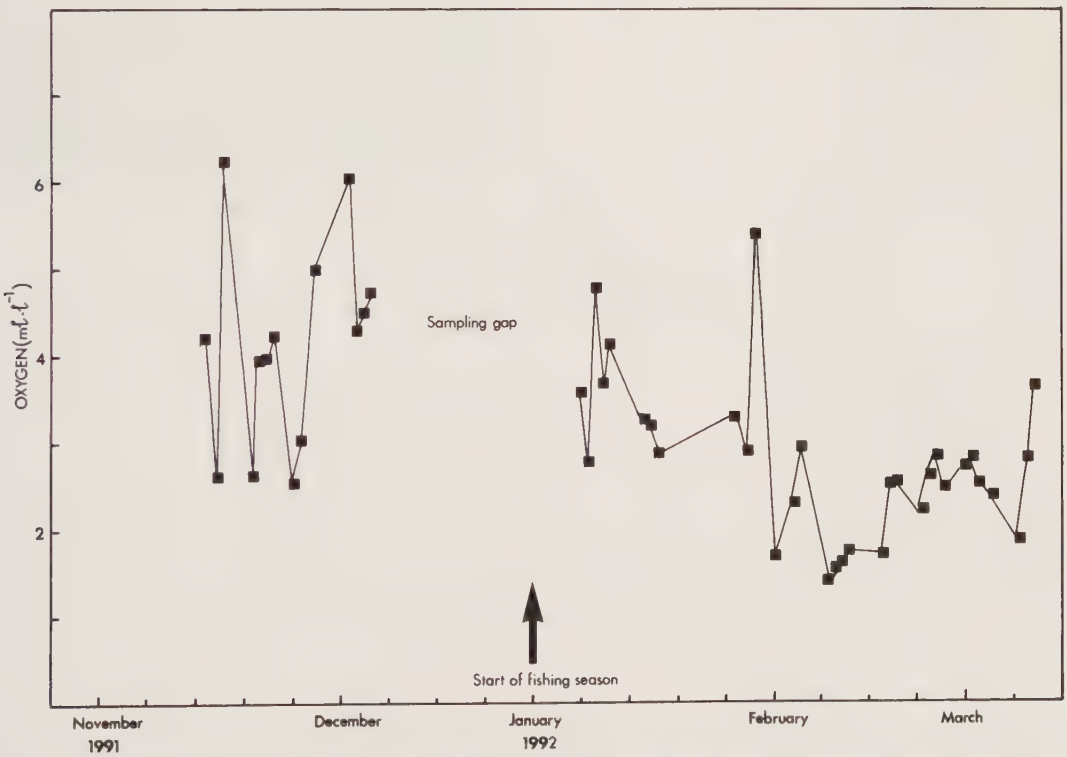

Fig. 23: Oxygen concentrations in the bottom layer at the monitoring station in Saldanha Bay, November 1991–March 1992

enrichment may be occurring throughout the harbour area. The year 1991 also saw the establishment of a new, long-term monitoring station at one of the mussel farms, which has shown some interesting preliminary results on the variability of oxygen in the bottom water (Fig. 23). Although the record is still too short to allow detailed interpretation, it does reveal the potential vulnerability of West Coast bays, with their water naturally low in oxygen, to additional organic loading.

It is envisaged that fieldwork in Saldanha Bay will be completed in 1992, after which it is likely that a similar project can be undertaken in Table Bay, which is situated adjacent to the next likely growth spine of Cape Town. The information and experience gained has greatly improved ability to make constructive contributions to local management.

3.7 The environmental impact of mariculture

ONE other important consequence of the Saldanha Bay project has been an increased awareness of the potential environmental impact of mariculture. Interest in this industry has increased rapidly in South Africa in recent years, and permits have been issued for the farming of abalone (Fig. 24), oysters, mussels, prawns, redbait and clams. Although mariculture is dependent on the high quality of water, it can itself have negative impacts as a result of increased organic loading or the introduction of parasites, pathogens or exotic species.

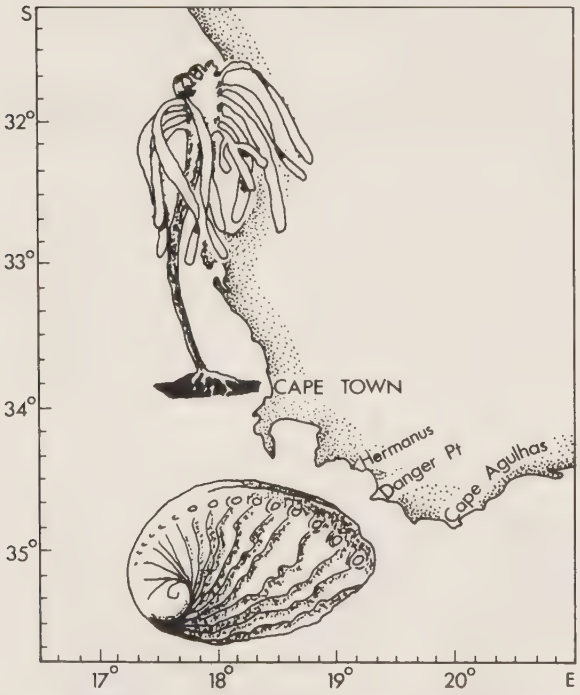

Fig. 24: Elements involved in the experimental abalone farms at Danger Point — the projected marketable product is a two-year-old abalone with a shell width of 5 cm

The information generated on the high variability of oxygen levels in Saldanha Bay (see Fig. 23) therefore has important implications for the mariculture industry there. For this reason an Institute Working Group has been created to discuss research aims in the light of past and future developments in mariculture. Among the projects undertaken will be the development of techniques to determine the carrying capacity of water bodies such as Saldanha Bay. This work involves modelling the organic loading resulting from mariculture operations together with flushing rates of the Bay, and should facilitate better management of the industry.

3.8 Krill and C-CAMLR

RESEARCH on Antarctic krill *Euphausia superba* undertaken by the Institute aims to improve knowledge of the species' abundance, distribution and ecology. Results have provided crucial input to the development of a rational management plan for the international krill

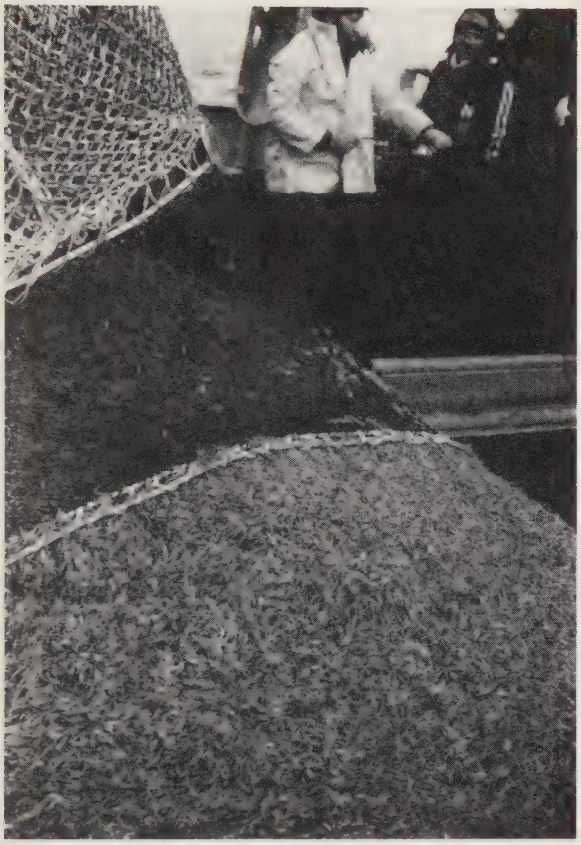

Fig. 25: A large catch of krill made from F.R.S. *Africana*

fishery. They were used by the 22-nation Commission for the Conservation of Antarctic Marine Living Resources (C-CAMLR) to set a precautionary catch limit of 1,5 million tons in C-CAMLR Statistical Area 48, where some 95% of the total world catch of krill is made (Fig. 25). One of the Institute's scientists (Mr Denzil Miller) convenes C-CAMLR's working group on krill, a group which has provided the scientific information and advice on which this precautionary catch limit was based. Work on the potential yield of krill carried out by the Institute in conjunction with the University of Cape Town is being utilized in further development of the precautionary management approach within C-CAMLR.

In 1991, Institute research led to improved definition of the characteristics of krill aggregation, important for developing an index of the species' abundance. The first reported measurements of within-aggregation density, which allow for acoustic beam effects, were made. This is essential to improving current understanding of krill aggregation dynamics.

As a result of a research grant awarded by the Royal Society in London, Mr Miller will study at the British Antarctic Survey in Cambridge for two months during 1992. During his visit he will collaborate with British scientists researching krill distribution and aggregation behaviour with a view to developing future cooperative studies. He will also address the Royal Society.

* * *

4. PUBLICATIONS

THE 222 original works listed in which the Sea Fisheries Research Institute was involved in 1991 are the most ever produced. Two numbers of the *South African Journal of Marine Science* (Nos 10 and 11) were produced, containing 72 papers. Although the contributions to Benguela–91 (*Benguela Trophic Functioning*) will be published in 1992 as No. 12 of the Journal, advance abstracts of 65 oral and poster presentations with staff involvement are listed, boosting non-SFRI local publications to 100. Apart from this, staff participated in 49 papers overseas. The results of a 27-day Anchor Station study in 1987 were published as a suite of nine papers in *Progress in Oceanography*. Also, staff were involved in seven papers published in 1991 in the *Transactions of the Royal Society of South Africa* and emanating from a symposium: False Bay 21 Years On — an Environmental Assessment, held in 1989. An informative booklet, *Surf and Shore/See en Strand*, sponsored by a fishing company, was produced for National Marine Day. Finally, the first in a popularized information series, *Marine Pollution/ Mariene Besoedeling*, was issued.

Of the 222 works listed, 105 were by staff members only and 37 by outside colleagues publishing in the house series, the remainder being cooperative efforts. In all, 220 different authors (89 staff, 95 other local and 36 overseas) participated in the publications.

4.1 Publications involving staff and directly contracted staff

ANDERSON, R. J. 1991 — Seasonal sand-burial as a community determinant on a South African west coast rocky shore. Program of the IVth International Congress and Annual Meeting of the Phycological Society of America, Duke University, South Carolina, August 1991: p. 44 (Abstr.)

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ANDERSON, R. J., SIMONS, R. H., JARMAN, N. G. and G. J. LEVITT 1991 — *Gelidium pristoides* in South Africa. *Hydrobiologia* **221**: 55–66.

ARMSTRONG, D. A., VERHEYE, H. M. [S.] and A. D. KEMP 1991 — Short-term variability during an Anchor Station study in the southern Benguela upwelling system. Fecundity estimates of the dominant copepod, *Calanoides carinatus*. *Prog. Oceanogr.* **28**(1–2): 167–188.

ARMSTRONG, M. J., CHAPMAN, P., DUDLEY, S. F. J., HAMPTON, I. and P. E. MALAN 1991 — Occurrence and population structure of pilchard *Sardinops ocellatus*, round herring *Etrumeus whiteheadi* and anchovy *Engraulis capensis* off the east coast of southern Africa. *S. Afr. J. mar. Sci.* **11**: 227–249.

ARMSTRONG, M. J., JAMES, A. G. and E. S. VALDÉS SZEINFELD 1991 — Estimates of annual consumption of food by anchovy and other pelagic fish species off South Africa during the period 1984–1988. *S. Afr. J. mar. Sci.* **11**: 251–266.

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ARMSTRONG, M. J. and P. A. SHELTON 1990 — Clupeoid life-history styles in variable environments. *Environ. Biol. Fishes* **28**: 77–85.

ATTWOOD, C. G., MONTEIRO, P. [M.] S. and M. I. LUCAS 1991 — An investigation into the balance of CO_2 at the ocean surface at an upwelling region and at an oceanic front. Programme and Abstracts of an International Symposium: Benguela Trophic Functioning, Cape Town, September 1991: p. 172 (Poster).

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AUGUSTYN, C. J., LIPIŃSKI, M. R. and W. [H. H.] SAUER 1991 — Can the *Loligo* squid fishery be managed effectively? Programme and Abstracts of an International Symposium: Benguela Trophic Functioning, Cape Town, September 1991: 95–96.

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